WAVE GUIDE TESTING WITH NANOSECOND R-F VOLTAGE PULSES

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THESIS

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by

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Waveguide Testing With Nanosecond

R-F Voltage Pulses

by

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ABSTRACT

The testing of waveguide systems was demonstrated using nano-second r-f voltage pulses. Pulse generation was effected by d-c coupled pulse grid modulation of a traveling-wave tube. This d-c modulation pulse was produced through the use of a fast thyratron circuit. Resultant r-f voltage pulses were used to drive a waveguide system and reflections from waveguide obstructions were viewed on a high-speed sampling oscilloscope. The location and reflection coefficients of obstructions were then obtained from measurements taken on the oscilloscope face.

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ACKNOWLEDGMENTS

Very sincere appreciation is expressed to Professor David B. Hoisington for his seemingly limitless patience and continued excellent guidance while acting as advisor for this project.

Further acknowledgment is due my wife for her timely aid and encouragement.

I. INTRODUCTION

Present methods of time-domain reflectometry utilizing fast rise-time d-c pulses have an inherent defect when used in waveguide testing. Such pulses are characterized by a frequency spectrum too large to be handled by the waveguide. The high-frequency components are normally propagated, but most of the energy is in the low-frequency components (below waveguide cut-off frequency), and these are rapidly attenuated.

Initial investigation showed that the use of r-f voltage pulses for time-domain reflectometry of waveguides was superior to the fast rise-time d-c pulses [1]. Time-domain reflectometry of waveguides is a means by which the amplitude and propagation time of obstruction reflections are measured through the use of extremely short r-f pulses. The amplitude measurements allow the calculation of obstruction reflection coefficients and the propagation time can be used to determine obstruction location.

This initial research was limited to the use of unbiased crystal detection of such r-f pulses, because no high-speed oscilloscope was available to view them directly. Such direct viewing of microwave signal pulses might allow later phase-coherent methods to be devised and phase information to be measured.

Meanwhile, a high-speed sampling oscilloscope became available for research work which provided a means by which microwave pulses through X-band could be viewed directly. An improvement of the initial pulsing circuitry was necessary before implementation of a technique employing the sampling oscilloscope could be accomplished. Further, alternate methods of pulse generation were considered for the purpose of replacing the original with an improved and more compact system.

Even though pulse generation was to be effected in only X-band because of greater availability of equipment, the final method was to be easily adaptable to all waveguide frequency ranges up through X-band. Further, the method was to provide nanosecond range pulses for high accuracy, but not of such a short duration that delay distortion due to broad spectrum bandwidth would become a factor. Tolerable delay distortion was to be defined and associated allowable pulse duration, waveguide bandwidth and waveguide lengths were to be determined.

Ideally the final system was to be a short-range extremely accurate special-purpose radar which would also provide information concerning obstruction size. Further refinements which would allow for determining phase information and possibly more complete obstruction characteristics were left for later research.

II. PULSE METHODS CONSIDERED

A. INTRODUCTION

Various methods for the generation of short r-f pulses were considered during the course of this research. Descriptions will follow concerning those listed below:

1. Comb Generator
2. Waveguide/Coaxial Diode Switches
3. TR-tube Breakdown

For flexibility, only generation methods extendable to most microwave frequency ranges were considered.

B. COMB GENERATOR

The comb generator is a device designed to provide a train of very short d-c voltage pulses. One type (Hewlett Packard model 33003A) produces pulses which may have 10-volts peak amplitude and 200-pico-second duration dependent upon input sign-wave amplitude and frequency. Pulse generation is effected through the use of snap or step-recovery diodes. These diodes exhibit a low impedance during forward conduction and will switch rapidly to a high impedance after stored charge is removed. Thus, action as a charge-controlled switch results [2]. Various manufacturers market comb generators and this device was considered in two applications for the generation of nanosecond pulses.

One method was to apply the d-c pulse generated by the comb generator directly to the grid of a traveling wave tube (TWT) biased below cut-off. These pulses would drive the TWT into conduction resulting in short-burst amplification of a microwave input.

Another method considered was concerned with the very wide spectrum of the d-c pulse. This spectrum includes lines at multiples of the input drive frequency to above X-band. By applying the d-c pulse directly to the input of the TWT, only the spectrum within the frequency range of the TWT would be amplified, thus allowing the TWT to act as a band-pass filter. If more discrete frequency ranges were needed, a filter arrangement could be used to select the band of frequencies desired [3].

Unfortunately, available comb generator pulses, while of sufficient amplitude and short duration, have a pulse repetition frequency (PRF) too high for reflectometry applications with long waveguides. Moreover, as the sine-wave input drive is lowered in frequency, the d-c pulse output becomes longer and base line noise is increased. The lowest frequency at which available comb generators can presently be driven is 10 MHz. At this frequency, only waveguides to 30 meters in length could be checked without encountering second-time-around echoes and thus providing possible erroneous information. Further, a frequency of 100 MHz or higher was necessary for good pulse formation.

At first, it was believed that gating the filter input could solve the high PRF problem. That is, the sine-wave input would be gated to provide one cycle of 100 MHz at a one-MHz rate. However, it was discovered that the comb generator has a long build-up time (order of milliseconds). Therefore, to use the comb generator, it would be necessary to gate the output at the desired rate. Possibly, a circuit could be designed which would gate off the TWT by square-wave negative bias while the comb generator operates in a steady-state condition. In this manner, an effective lowering of comb generator PRF might be achieved by allowing amplification by the TWT of only one in one hundred of the comb generator pulses. Time considerations precluded this being accomplished.

C. WAVEGUIDE/COAXIAL DIODE SWITCHES

The generation of short microwave pulses has recently been made possible by new developments in microwave diode switches. Switches are marketed that are capable of switching times as fast as one nanosecond with power-handling capabilities up to 10 kW and frequency ranges from UHF to K-band. These switches are available in either waveguide or coaxial configurations. The coaxial configuration would be more advantageous for reflectometry applications since it could be used to test all waveguides by merely changing output connections and microwave sources.

Two methods of short pulse generation will be discussed that use these diode switches. The first method is simply the use of the fast diode switching time to turn on and off a microwave source. Very recently, Microwave Associates has marketed a high-voltage triple-barrier Schottky diode which, with its total capacitance of only one picofarad, is capable of switching times as low as 30 picoseconds. However, again, time and cost considerations precluded the experimental investigation of such devices.

The second method is being coincidently investigated separately in another thesis project [4]. This method incorporates an iris-feed cavity consisting of a short length of waveguide with a high-speed microwave SPST switch used as the shorted end. When the switch opens (changes to an "on" condition, "dumping" the cavity), a very narrow pulse results. This pulse duration is directly proportional to the cavity length. The peak pulse amplitude is a function of the cavity Q, and a resultant gain in power from that provided by the microwave source results. Signal enhancements in the order of 6 db have been demonstrated; that is, pulse output 6 db greater than signal generator output. If diode switch losses could be lowered, much higher gains could be expected.

D. TR-TUBE BREAKDOWN

It has long been known that the isolation provided to radar receivers by TR-tubes was not complete. The spike of power allowed to feed directly through the TR system to the receiver from the large transmitted pulse decreased the receiver crystal detector lifetime. Such spikes have been measured to be from one to four watts peak with typically about 1.5-nanosecond duration [5]. The TR-tube pulse follows the transmitted pulse ramp until TR firing threshold is attained. Upon TR-tube firing the spike decays to zero within one nanosecond. Thus, there is little dependance of spike duration upon transmitter peak power.

This narrow pulse of power could lend itself to time-domain-reflectometry applications quite easily. Radars could by this means provide their own test pulse for waveguide checking. A means by which the radar transmitter pulse could be dissipated into a dummy load and the TR-tube breakdown pulse sent toward the antenna could be devised simply in many radar types. Coincidently, a provision for the sampling of reflected power would be made.

However, the slow PRF of most radars would not readily lend itself to wide-band sampling oscillographic techniques of examining r-f voltage pulses.

III. THYRATRON PULSER

A. BACKGROUND

Previous research had been conducted at this institution utilizing nanosecond pulses for waveguide testing [1]. The use of a thyratron pulser circuit to grid modulate a traveling-wave-tube amplifier for the production of nanosecond r-f pulses was demonstrated. Since this method was known to be successful, and since the required components were readily available, it was decided to extend the development of this basic circuitry.

This circuitry utilized the switching properties of a 2D21 thyratron to produce a d-c voltage pulse. When the thyratron fires, a capacitor charged to a high voltage in the thyratron plate circuit is impressed across the resistance in the cathode. This cathode voltage pulse is then differentiated, thereby producing a short d-c pulse of approximately 30 volts peak amplitude and 10 nanoseconds duration at the .707 point. This pulse is then applied to the grid of a TWT biased slightly below cutoff causing the tube to conduct, amplifying the microwave input and thus providing short r-f pulses at the output.

However, the original pulser model had to be improved upon before further work could be done. In the new system the pulser was to be used in conjunction with the HP 140A sampling oscilloscope for the purpose of viewing direct r-f voltages rather than detected r-f pulses as was done previously. The HP 140A with 1411A, 1425A plug-ins and 1431A sampler can be used for signals from dc to 12.4 GHz.

However, in the X-band region, a PRF of only 10 KHz did not provide enough samples to view the signal directly. Since integration by means of photographic time exposure would not be convenient, and since the original pulser was optimized for 10 KHz, an alteration was necessary. It was also determined that if a larger voltage could be produced, the TWT could be biased further into cutoff and a narrower portion of the d-c pulse could be used to produce shorter r-f spikes.

The output leads of the original circuit carried the cathode pulse 18 inches before differentiation took place at the TWT grid connector. It was considered highly probable that output lead stray capacitance and inductance degraded the pulse. Moreover, stray capacitance and component placement of the hand-wired circuit were considered to be the probable source of the small spurious oscillations observed in the cathode and differentiated-output pulses. Additionally, a great deal of thyratron sensitivity to the width of the rectangular drive pulse was observed. As the width was reduced, thyratron output pulse amplitude rapidly decreased or stopped entirely.

B. REFINEMENTS

The maximum attainable PRF is a function of the thyratron deionization time. The 2D21 has an inherent deionization time which cannot be reduced, and therefore a search was made for another tube type. Three were discovered which could provide faster deionization times, the 5696, 5663, and the 502-A [6]. The 502-A is rated for the shortest deionization time, but is obsolete and no longer available. The 5663 is slightly better than the 5696; however, it has other shortcomings to be discussed later.

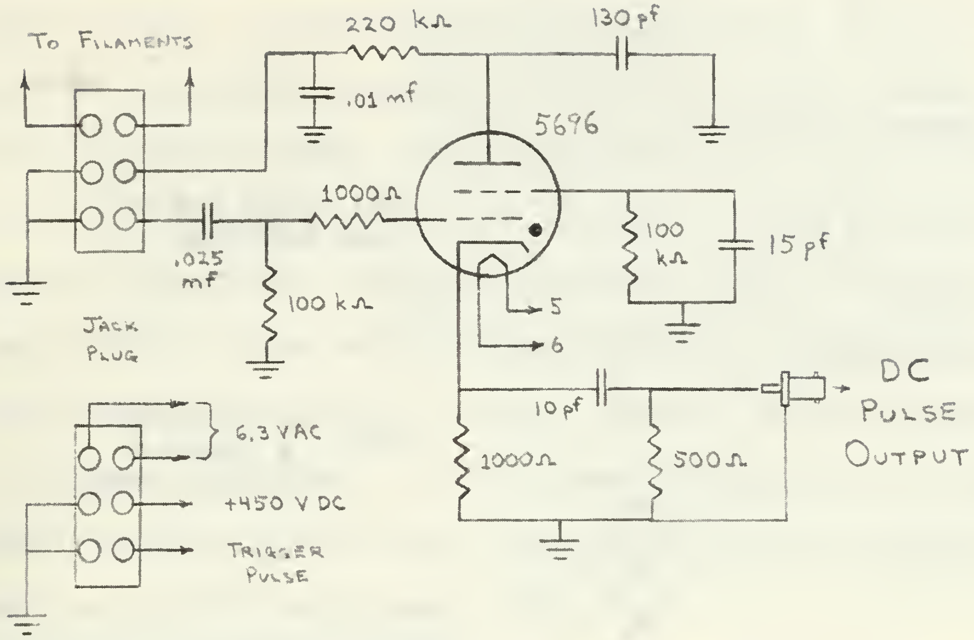
Utilizing the 5696 and breadboarding the initial circuit, it was found that lowering plate resistance from 300k to 220k ohms optimized the amplitude of the output pulse without degrading the short duration time. Also, a reduction of sensitivity to the width of the rectangular drive pulse was achieved by increasing the input coupling capacitor from 100 pf to .025 mf.

The plate inductance of the original circuit was in the order of microhenries and provided negligible effect at the repetition frequencies used. To have an effect at the frequency of operation, an inductance of at least 125 mh would have been required. Such an inductor was physically too large to be included in the final circuit.

The successful reduction of stray capacitance and elimination of spurious oscillations were achieved by rewiring in a printed-circuit configuration. The modified design featured, in addition to compactness, a provision for the differentiated pulse to be directly coupled to the TWT grid-modulation jack. The resultant circuit schematic and thyratron pulser are shown in Figures 3-1 thru 3-3.

C. PERFORMANCE

Since the 10-KHz PRF of the original modulator did not provide an adequate display on the sampling oscilloscope, and since the 5696 thyratron did not provide a short enough modulating pulse at frequencies above 50 KHz; a compromise had to be made. Figure 3-4 is a graphical representation of modulating voltage versus PRF for three different 5696 thyratrons. This figure shows a variation of output voltage between various 5696 tubes, sometimes severe. Therefore, tube variation also became a factor in deciding on the final PRF.



THYRATRON PULSER SCHEMATIC

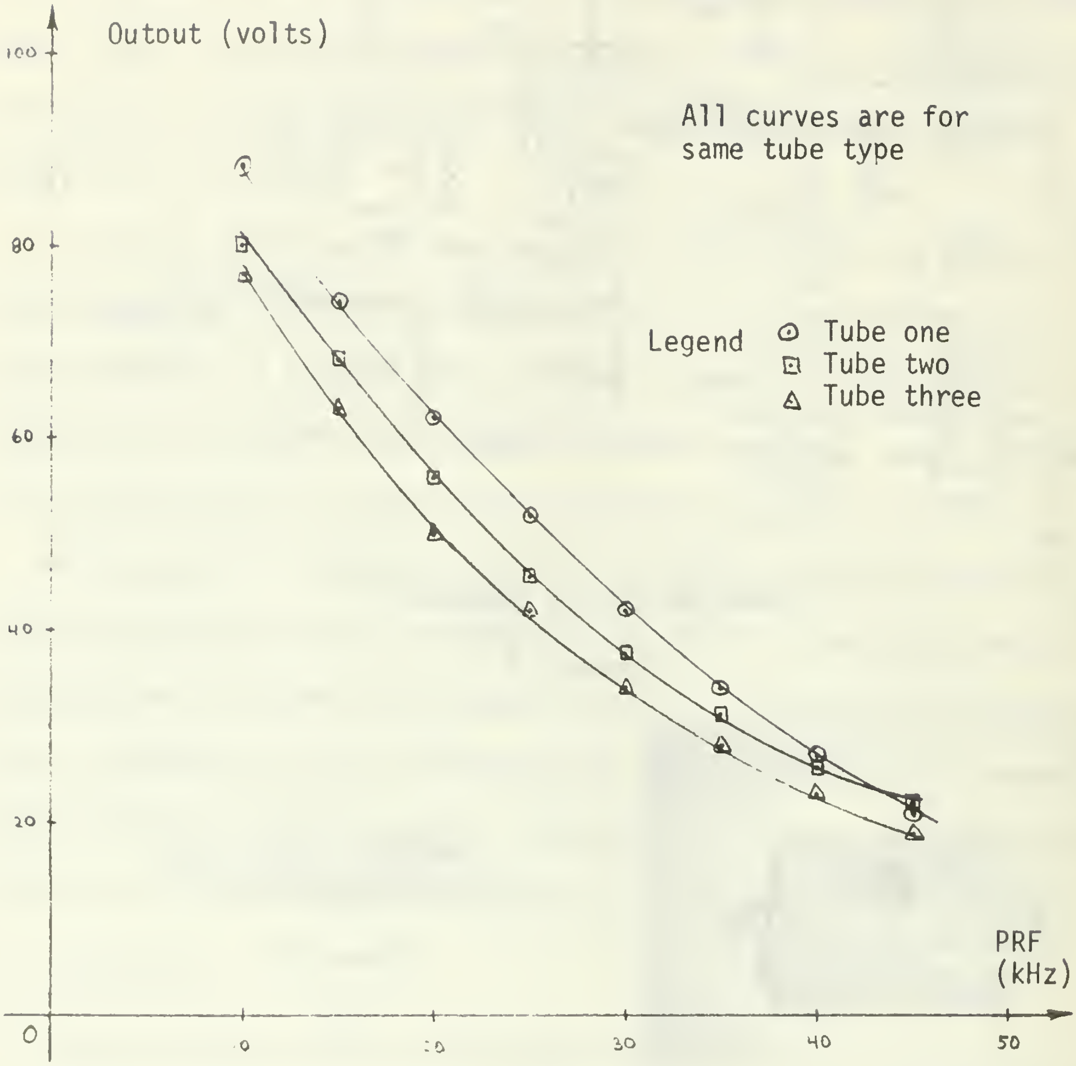
Figure 3-1

THYRATRON PULSER VIEW
(WITHOUT COVER)

Figure 3-2

THYRATRON PULSER VIEW
(WITH COVER)

Figure 3-3

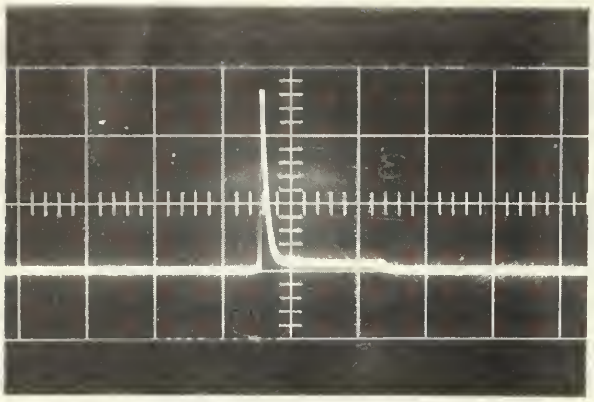


GRAPH OF PULSER OUTPUT VOLTAGE
VERSUS PULSE REPETITION FREQUENCY

Figure 3-4

It could be observed that peak thyratron plate voltage never reached supply voltage, and therefore some increase in plate voltage supply could be made without exceeding tube voltage maximums. However, care had to be taken in order not to exceed maximum peak-current levels listed for the tube. Peak-current limitations of the 5696 thyratron were far greater than those of the 5663, and 5663 was therefore abandoned. A final plate-supply voltage of 450 volts was decided upon. Any voltage greater than this severely degraded the useable lifetime of the tube. For example, one test showed that modulating voltage output decreased by 35 per cent after one-half hour of sustained operation with 500 volts supply.

By experimentally varying the PRF and observing r-f voltage output, a useful PRF operation range of 7.5 to 25 KHz was established. R-f pulses could be obtained with two to four-nanosecond duration measured at .707 of peak amplitude. Typical output is portrayed in Figures 3-5 thru 3-10.



CATHODE VOLTAGE PULSE BEFORE DIFFERENTIATION PRF = 20 kHz

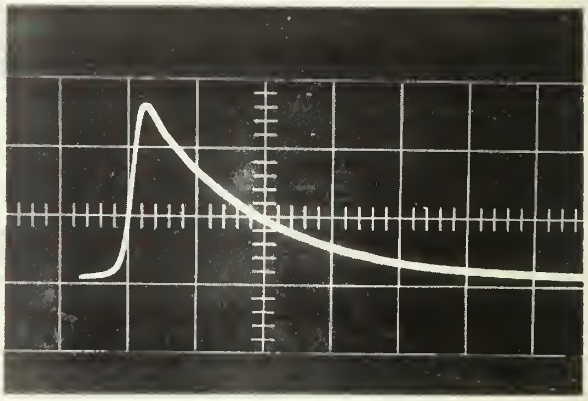
100 V/cm
2 μs/cm

Figure 3-5

CATHODE VOLTAGE PULSE OF FIGURE 3-5 EXPANDED SCALE

100 V/cm
100 ns/cm

Figure 3-6



RESULTANT DIFFERENTIATED OUTPUT VOLTAGE PULSE

10 ns/cm
10 V/cm

Figure 3-7

TYPICAL R-F PULSE OUTPUT

PRF 25 kHz
100 mV/cm
10 ns/cm
10 db attenuation

Figure 3-8

TYPICAL R-F PULSE OUTPUT

PRF 15 kHz
100 mV/cm
10 ns/cm
10 db attenuation

Figure 3-9

MINIMUM DURATION, MAXIMUM AMPLITUDE
OBTAINED FOR R-F VOLTAGE PULSE

200 mV/cm
10 ns/cm
10 db attenuation
17.5 kHz PRF

Figure 3-10

IV. TEST PROCEDURE AND PRELIMINARY WAVEGUIDE INVESTIGATIONS

A. INTRODUCTION

After nanosecond r-f pulse generation was achieved, a test procedure by which waveguide faults could be located and measured was needed. It was desired to make this procedure as uncomplicated as possible, and to incorporate only readily available equipment. Additionally, crystal detection of r-f pulses was compared with direct readout of pulse voltage to determine relative suitability in reflectometry applications.

B. TEST PROCEDURE

After the nanosecond r-f pulses were developed, they were fed through a waveguide to a 10-db directional coupler which provided a monitor of the r-f pulses for TWT tuning purposes (refer to the block diagram in Figure 4-1). During testing, this monitor also provided a constant check of the input r-f pulse amplitude. Next, a four-port circulator passed the pulses to the test waveguide through port two, and a manual shorting switch. Returning reflections were monitored from port three through a precision attenuator and port four, connected to a dummy load, provided isolation for the TWT and oscilloscope. Synchronization of the sampling oscilloscope was provided by a drive pulse generator which also activated the thyratron pulser.

Before a waveguide test could be accomplished, two measurement quantities were needed, group velocity and waveguide attenuation factors of the test waveguide. By making all measurements with reference to the manual shorting switch, the attenuation and velocity factors of the test equipment were eliminated.

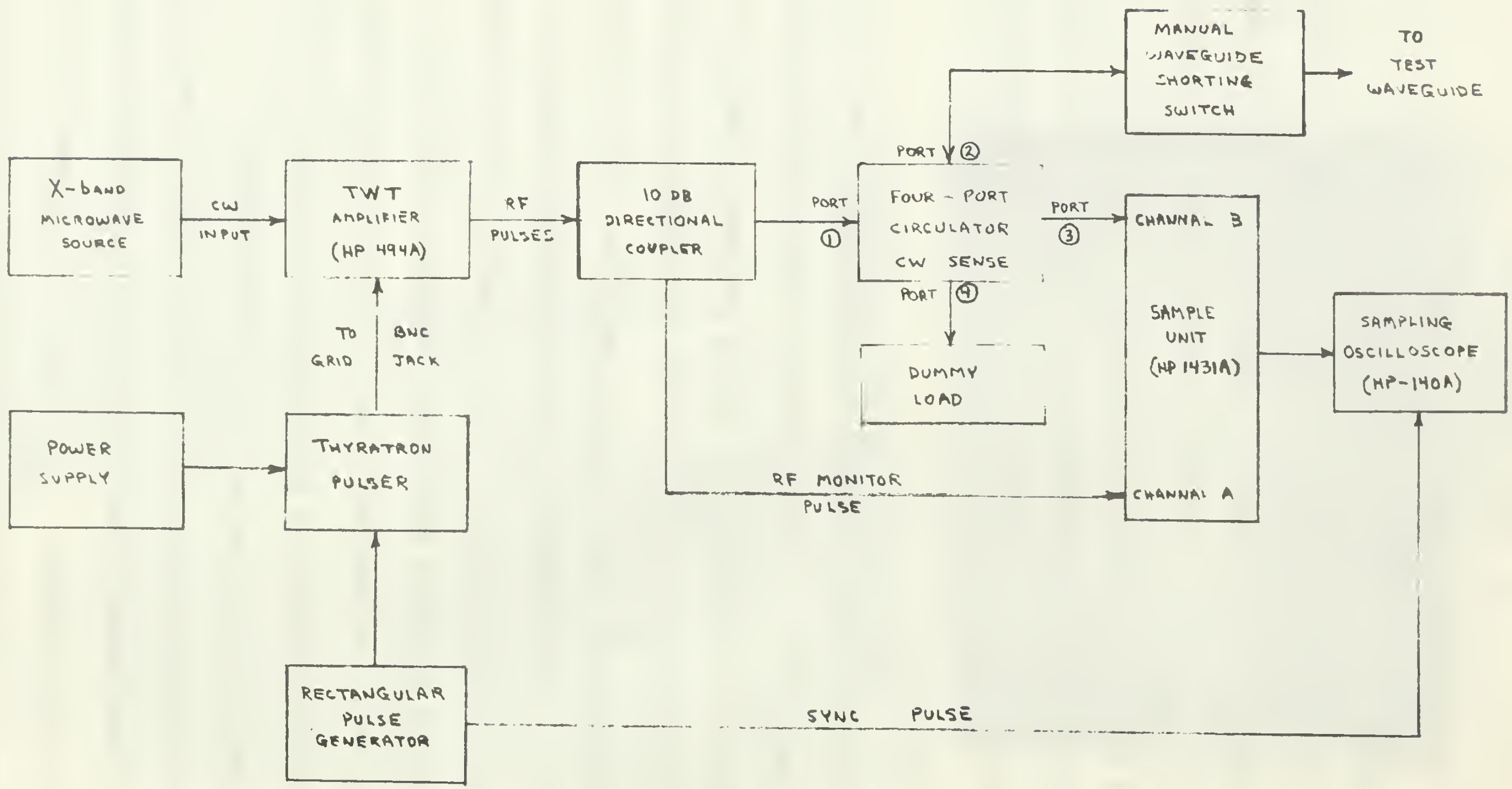


FIGURE 4-1

BLOCK DIAGRAM OF EQUIPMENT

A waveguide test section of known length shorted at the far end was connected to the manual shorting switch (refer to figure 4-1). A time reference position was obtained by closing the manual short and noting the pulse position on the oscilloscope face. The shift in pulse position with the switch open allowed a measurement of pulse traverse time from the manual short to the far end of the test section and back. With this measurement the group velocity was calculated through the use of the following formula.

$$V_g = \frac{2L}{t} \tag{4-1}$$

where L = waveguide length

Measurements of group velocity for two types of X-band waveguide (RG - 52/U, RG - 51/U) were made with these results:

$$v_g = 2.00 \times 10^8 \text{ m/sec} \qquad \text{RG - 52/U}$$

$$= 2.44 \times 10^8 \text{ m/sec} \qquad \text{RG - 51/U}$$

In checking these values through the use of the following formulae[7], differences of 2.3 and 0.5 per cent respectively were found.

$$v_g = c\frac{\lambda}{\lambda_g} \tag{4-2}$$

$$\lambda_g = \frac{\lambda}{\left|\frac{\mu\varepsilon}{\mu_o\varepsilon_o} - \left(\frac{\lambda}{\lambda_c}\right)^2\right|^{1/2}} \tag{4-3}$$

$$\lambda_c = \frac{1}{\left|\left(\frac{m}{2a}\right)^2 + \left(\frac{n}{2b}\right)^2\right|^{1/2}} \tag{4-4}$$

where m & n are mode numbers

a & b are waveguide dimensions

For TE_{10} air-dielectric waveguide

$$v_g = c \left| 1 - \left(\frac{\lambda}{2a}\right)^2 \right|^{1/2} \tag{4-5}$$

or

$$v_g = 2.050 \times 10^8 \text{ m/sec} \quad \text{RG - 52/U}$$

$$v_g = 2.434 \times 10^8 \text{ m/sec} \quad \text{RG - 51/U}$$

The attenuation factor was measured in a manner similar to group velocity. Again, a test section of known length shorted at one end was connected to the manual shorting switch. With this switch in the shorted position, a measurement of reflected r-f voltage in db was made and taken as incident pulse amplitude. Reflected pulse amplitude was measured with the switch open and the difference taken as db loss over twice the length of the test section. The reflection coefficient of each short was assumed to be unity. This attenuation factor was compared with the published values to insure correctness.

$$\alpha = \frac{\text{db loss}}{2L} \tag{4-6}$$

It was also compared with values obtained through the use of the following theoretical formula [8].

For copper waveguide TE_{10} mode

$$\alpha\left(\frac{db}{m}\right) = \left[\frac{0.0364}{a^{3/2}}\right] \left[\frac{.5(a/b)(f/f_c)^{3/2} + (f/f_c)^{-1/2}}{((f/f_c)^2 - 1))^{1/2}}\right. \tag{4-7}$$

The measured values were in each case greater than the theoretical values. For example, in RG-52/U, copper waveguide at 8.515 gHz, the following results were obtained

α = .265 db/m measured

α = .107 db/m calculated

Formula 4-7 is idealized and does not take into account such waveguide imperfections as dust, non-linearities, etc. These imperfections caused added attenuation of the pulse power. Since the segments of waveguide tested portrayed many of the foregoing imperfections, it is believed that the measured values are the more accurate.

Once the waveguide group velocity and attenuation factors were known, waveguide fault finding became a simple procedure. First, the waveguide was connected to the manual shorting switch. Next, with the switch closed, a measurement was taken of the incident pulse voltage and position on the sampling oscilloscope. The switch was then opened and a display of waveguide reflections was obtained. The time of travel from the shorting switch position to the reflection of interest was then measured. This time measurement was converted to distance by use of the previously obtained group velocity. In this manner, waveguide obstructions were located.

Measurement of the reflection coefficient of a particular obstruction was secured by two different methods. The first method was to measure the reflected and incident voltages and to calculate their ratio. The second method was to make the incident voltage amplitude through a precision attenuator equal to that of the reflected voltage. The ratio of reflected to incident voltage was determined from this attenuation. In either case, the effect of waveguide attenuation on the reflected signal must be included in the final calculation. Recall here that the monitor pulse was observed throughout for any changes in amplitude which might have introduced measurement errors.

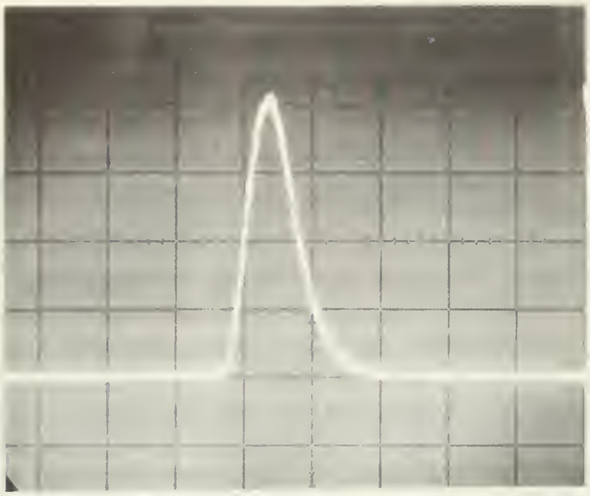
C. DETECTED VERSUS R-F PULSE METHODS

The wide-band sampling oscilloscope enables one to eliminate some inherent problems (calibration, low sensitivity) that exist when crystal detectors are used. The unbiased crystal detector does not respond with maximum sensitivity until a threshold voltage has been reached. Below threshold (dependent upon the type of material used in the crystal detector), the unbiased crystal detector operates with a non-linear square-law response. Sensitivity to small reflection coefficients is therefore low, making measurement difficult. However, utilizing sampling techniques with oscilloscopes capable of directly viewing the signal frequency in question, in this case X-band, linear operation is obtained, and hence a much wider dynamic range of measurements. The HP 140A oscilloscope with proper associated equipment, for example, is such an oscilloscope and is capable of viewing signals as small as one mv. Therefore, incident voltage pulses of 300 mv will allow standing wave ratios as small as 1.007 to be measured. Much higher incident powers are required with crystal detection than with r-f sampling oscillography in time-domain reflectometry techniques. Refer to Figures 4-2 thru 4-5 for a portrait of the foregoing effect.

Figure 4-2 shows the maximum amplitude and minimum duration obtainable for a detected pulse using only test equipment described, plus a 1N23WE diode in a tunable cavity mounting. This same pulse is shown in Figure 4-3 without detection. Notice that the amplitude is 300 mv greater. Moreover, the pulse shape indicates that the TWT was driven into saturation. By retuning the TWT, a better pulse shape, as shown in Figure 4-4, was obtained.

By using these pulses in a reflectometry application, a dramatic difference in sensitivity was demonstrated between detected and non-detected pulse methods. Figure 4-6 has much more information available than does Figure 4-5. Moreover, calibration problems are encountered when utilizing crystal detectors in reflectometry applications. If one crystal is to be used for incident pulse, and another for reflected pulse detection, the two should be matched closely or carefully calibrated, for accurate SWR measurements.

It is difficult and expensive to obtain two crystal detectors with matched output characteristics; and if the crystals are not matched, their output characteristic deviations need to be known. Even if one crystal were to be used for both incident and reflected pulse detection, accurate calibration is still necessary. Such calibration is not required when utilizing a wide-band sampling oscilloscope and r-f voltage pulses. However, in either case it is necessary to know the waveguide attenuation per unit distance.



DETECTED R-F PULSE

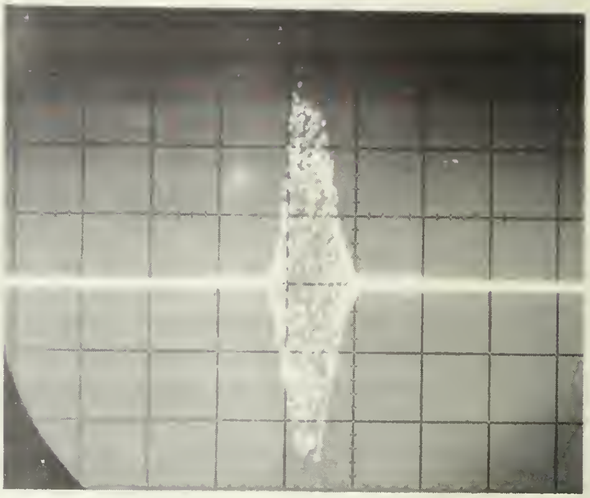
10 db attenuation
50 mV/cm
10 ns/cm

Figure 4-2

R-F PULSE BEFORE DETECTION

10 db attenuation
200 mV/cm
10 ns/cm

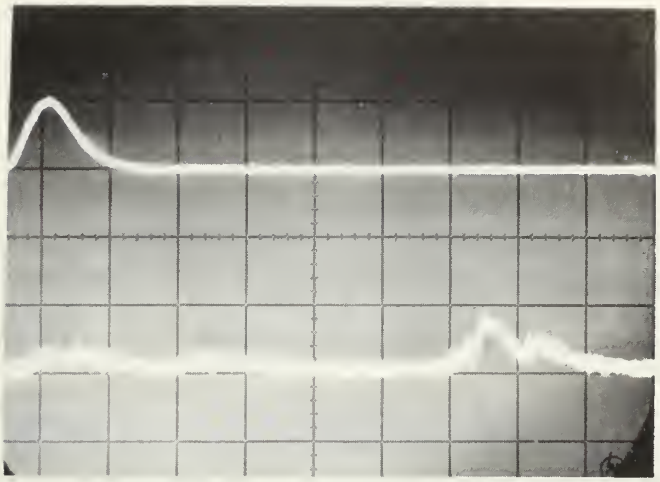
Figure 4-3



R-F PULSE AFTER RETUNING TWT

10 db attenuation
200 mV/cm
10 ns/cm

Figure 4-4



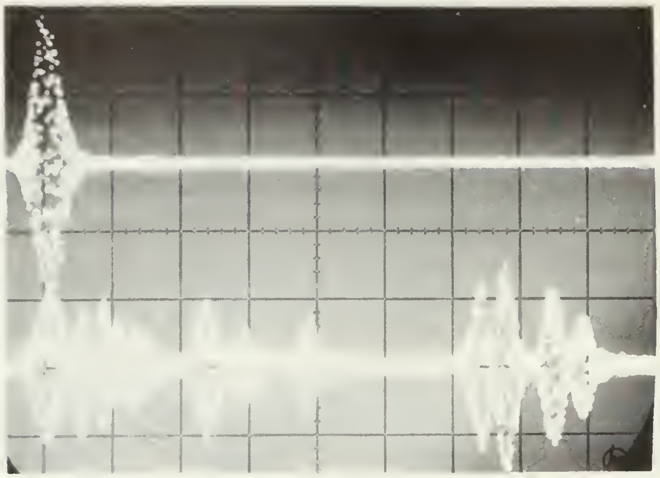
UPPER TRACE
INCIDENT DETECTED R-F

10 db attenuation
200 mV/cm
10 ns/cm

LOWER TRACE
DETECTED REFLECTIONS

0 db attenuation
10 mV/cm
10 ns/cm

Figure 4-5



UPPER TRACE
INCIDENT R-F VOLTAGE PULSE

10 db attenuation
100 mV/cm
10 ns/cm

LOWER TRACE
REFLECTED R-F VOLTAGE PULSES

0 db attenuation
20 mV/cm
10 ns/cm

Figure 4-6

V. WAVEGUIDE TESTING

A. BACKGROUND

There were three X-band waveguide systems available for testing at this institution. These systems were associated with the MK-13, MK-25, and SS radars.

A previous investigation of these installed systems utilized detected r-f pulses for locating obstructions and determining waveguide efficiency [1]. This work showed that the small reflections from flange joints affected the overall efficiency of these systems by approximately 2 per cent. Waveguide attenuation was the important factor in the determination of waveguide efficiency, because of the 50 to 100 - ft waveguide system lengths. At first it was suspected that the short duration test pulses used herein might be subject to delay distortion. Delay distortion is caused by a variation of group velocity for the various frequency components comprising the pulse. The distortion effect is directly proportional to the length of the waveguide. Calculations of permissable lengths were made utilizing the following formula [9].

$$BW = 19.5 \left(\frac{f}{f_c}\right)\left(\frac{f}{L}\right)^{1/2} (\delta\phi)^{1/2} \qquad (5\text{-}1)$$

where L = length of waveguide in kilometers

$\delta\phi$ = phase distortion in radians

Bandwidths of the 2.5-4.0 nsec test pulses at the 8.515 gHz test frequency were approximately 300 to 400 mHz and maximum allowable phase distortion was one radian. Calculations, using the foregoing data, showed that little distortion would occur in waveguide lengths to 90 ft. Since the longest waveguide system to be tested was approximately 100 ft , small delay distortion effects were expected.

B. WAVEGUIDE SYSTEMS

Figures 5-1 thru 5-6 show the construction and test results obtained from the MK-13 waveguide system. Each peak of the reflection waveform pattern was identified by a circled numeral, and this number was positioned on the waveguide system schematic. Notice that 1 denotes a position only 4.5 inch from reference. It was not presumed that such accuracy would prevail throughout the length of the waveguide since it was believed that the pulse group velocity varied slightly throughout the system. However, variations notwithstanding, accuracy to approximately one foot was demonstrated with the incident pulse of 3 nanoseconds measured at .707 peak amplitude. Initially it was presumed that the location of flange joints would become easily recognizable in the reflection waveforms; this was not always the case. Some flange joints were matched so well, or were so near an obstruction of larger reflection coefficient that their location could not be determined. Moreover, some less likely obstructions were easily detected as evidenced by 2, 3, 5, waveguide bends.

Figure 5-6 is the same as 5-2 except that the incident pulse duration was slightly longer, 4.2 as compared to 3 nanoseconds measured at the .707 point. In comparing these figures, notice the better definition provided by the 3-nanosecond pulse as evidenced by peaks 13, 14, and 15. Whenever a reflected pulse appears to be longer

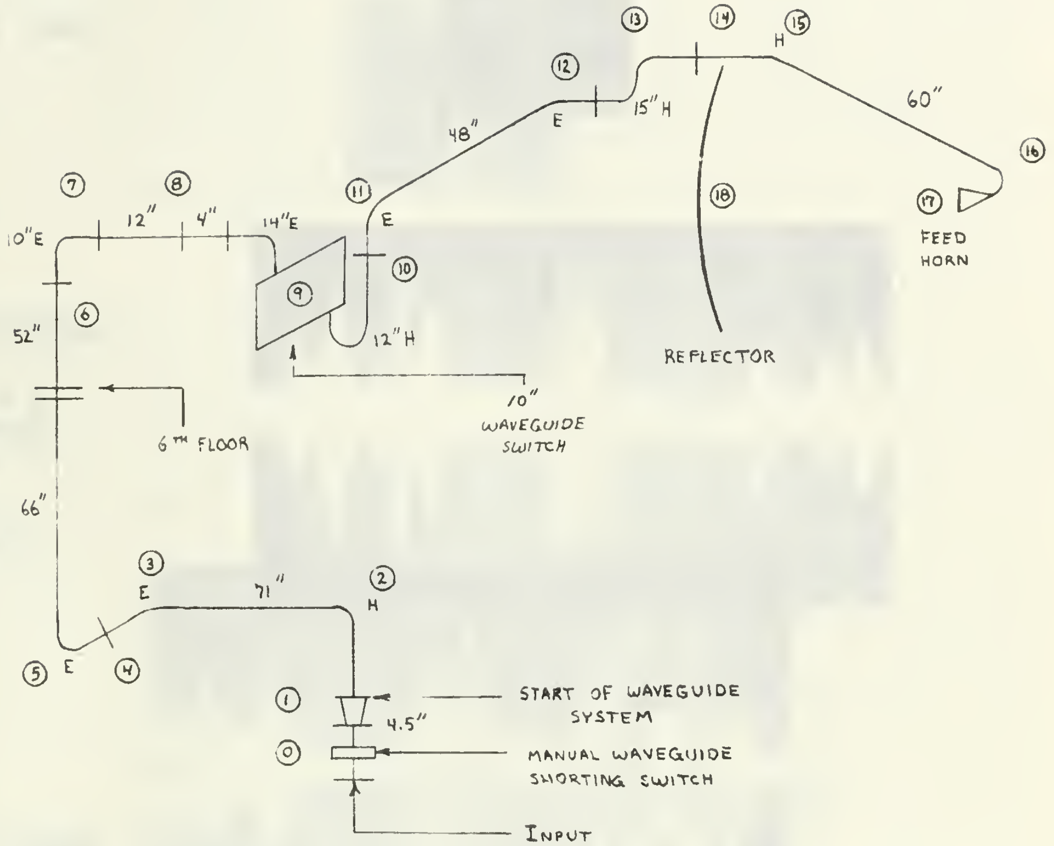


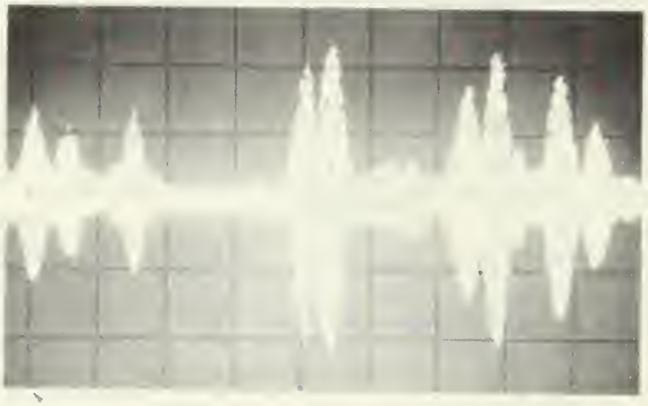
FIGURE 5-1

MK-13 WAVEGUIDE SYSTEM

MK-13 INCIDENT PULSE

10 db attenuation
100 mV/cm
10 ns/cm

Figure 5-2



WAVEGUIDE REFLECTIONS

0 db attenuation
20 mV/cm
10 ns/cm

Figure 5-3

Reference

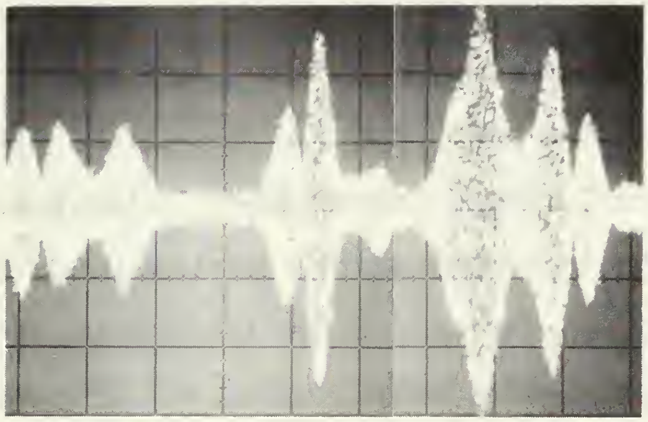
NUMBER DESIGNATION OF VOLTAGE PEAKS

Figure 5-4

MK-13 INCIDENT PULSE

10 db attenuation
100 mV/cm
10 ns/cm

Figure 5-5



MK-13 WAVEGUIDE REFLECTIONS

0 db attenuation
20 mV/cm
10 ns/cm

Figure 5-6

in duration than the incident, it can be safely assumed that it was in actuality two or more pulses nearly coincident, delay distortion notwithstanding.

The results obtained for the SS radar waveguide system are shown in Figures 5-7 thru 5-9. This system was the longest tested and did show slight delay distortion effects. These effects are mainly manifest in a spreading of the energy in the pulse. Such spreading could be detected in pulses traveling the longer distances. However the distortion was not detrimental to final test accuracy.

A small waveguide obstruction appears as 5 with no initial apparent cause in the reflection waveform. At first this waveform peak was believed to be due to a second reflection of a larger obstruction, but no evidence was noted to substantiate this fact. Therefore, it could only be assumed that this peak was caused by an obstruction other than construction flanges, bends, etc. Most likely a piece of dirt or minor waveguide irregularity occurs at this point. Also, peak 18 was the reflection obtained from the 65-ft 11-inch position. The two flanges and 5-inch E bend at this position should have given a larger reflection coefficient. Either the matching here is excellent or reflection cancellation occurs. It was not determined which factor caused the reflection coefficient to be lower than normally expected.

Figures 5-10 thru 5-13 are similar to those preceding except now the MK-25 waveguide system results are shown. The one notable difference with the reflection waveform as compared to those discussed previously is the large reflection numbered 13. The obstruction causing this reflection is shown in its worst-case condition which causes a reflection of 3.3 per cent of incident power. This loss of incident power was considered to be more than normally acceptable from a single waveguide obstruction. However, further investigation showed this particular obstruction to be a toggle waveguide arrangement which when in its antenna-stowed position has a slight open spacing. This spacing was considered normal and did not become a factor in the track-while-scan or scan modes of radar operation.

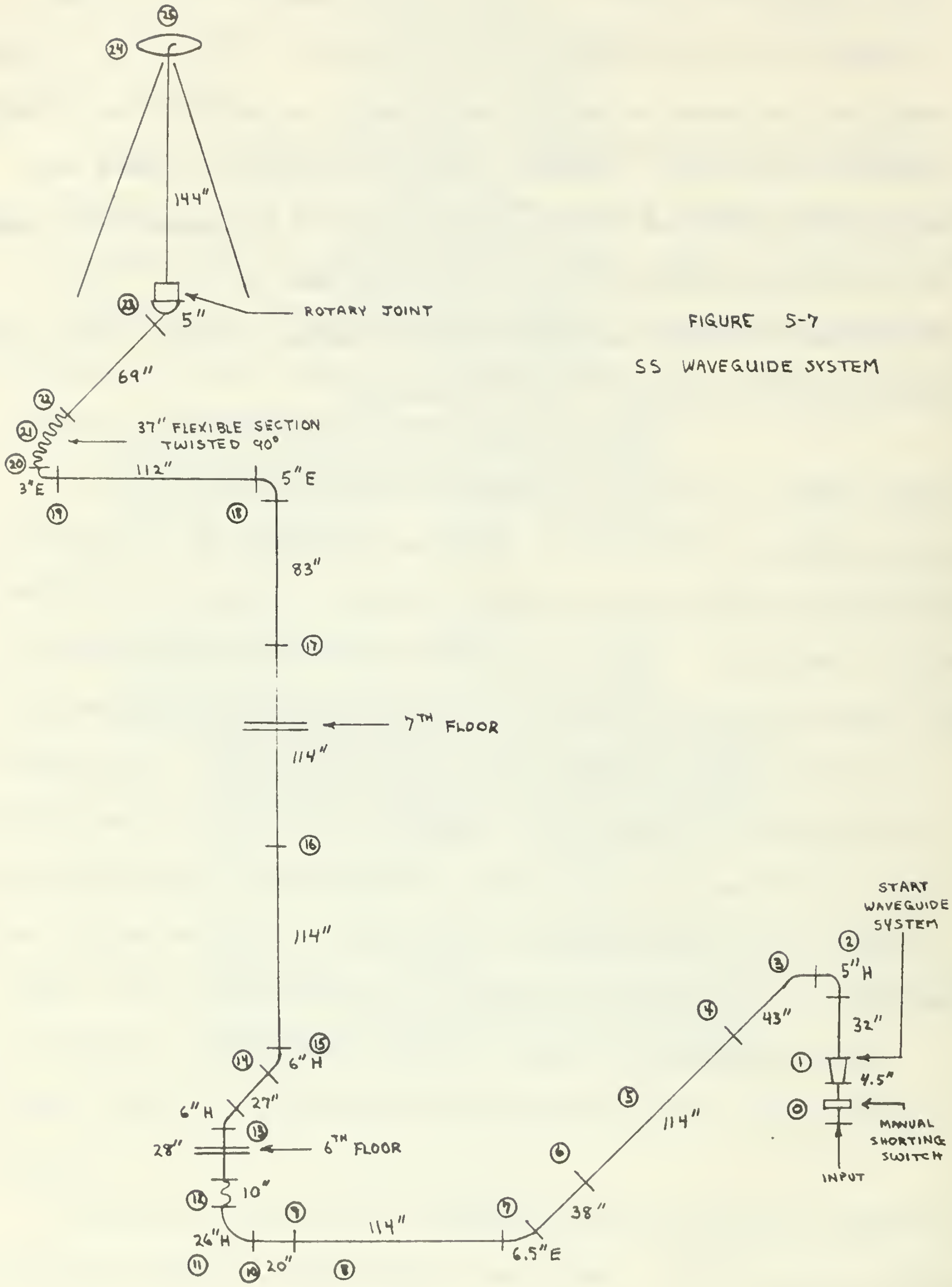


FIGURE 5-7

SS WAVEGUIDE SYSTEM

Figure 5-8 SS WAVEGUIDE REFLECTIONS 10 mV/cm, 10 ns/cm
INPUT PULSE SAME AS FIGURE 5-2

Figure 5-9 NUMBER DESIGNATION OF VOLTAGE PEAKS

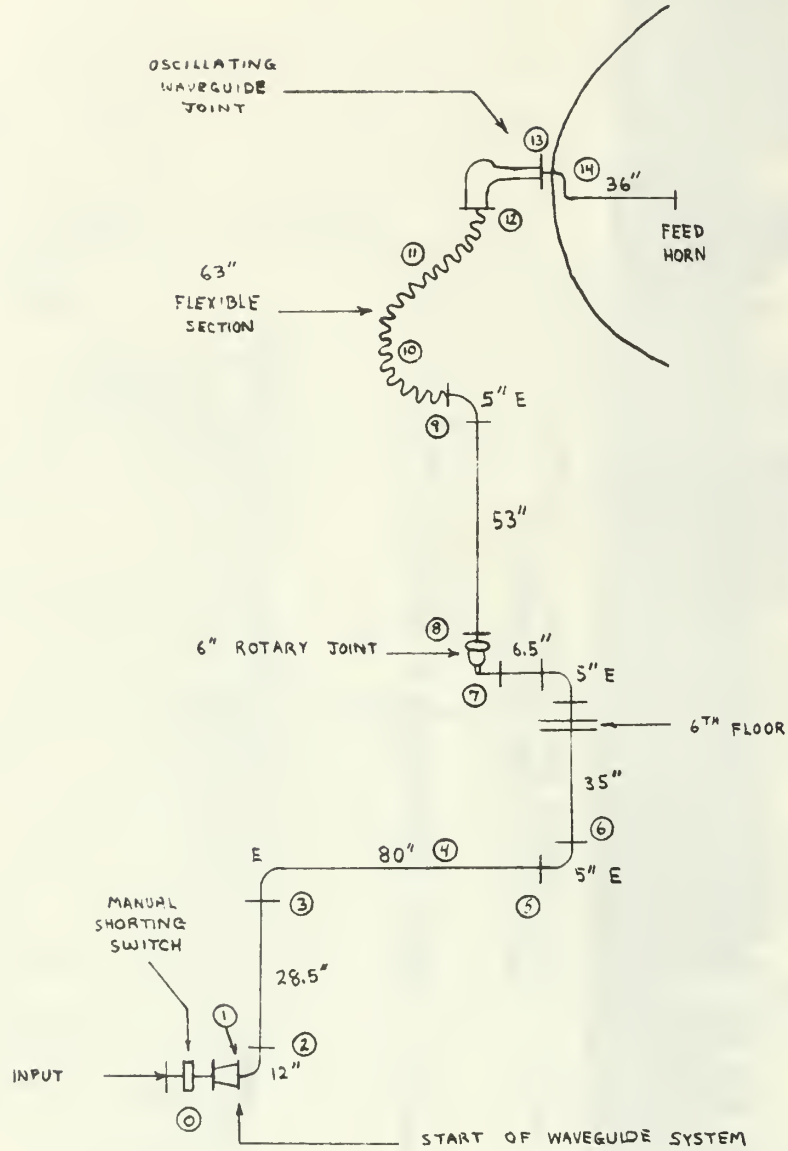
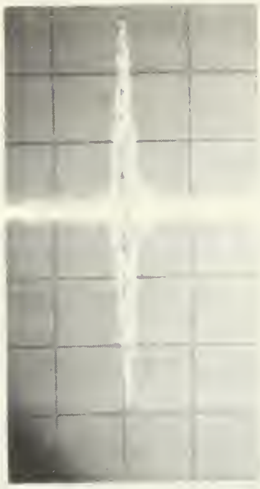


FIGURE 5-10

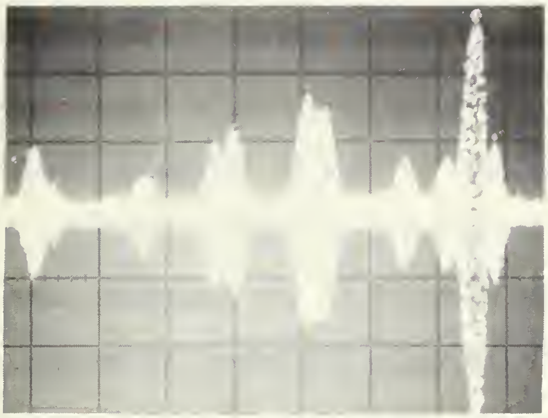
MK-25 WAVEGUIDE SYSTEM



INCIDENT PULSE MK-25

10 db attenuation
100 mV/cm
10 ns/cm

Figure 5-11



MK-25 WAVEGUIDE REFLECTIONS

3 db attenuation
20 mV/cm
10 ns/cm

Figure 5-12

NUMBER DESIGNATION
OF VOLTAGE PEAKS

Figure 5-13

VI. CONCLUSIONS

This research was conducted for the purpose of developing a method by which waveguide systems could be tested quickly and accurately. It was found that available equipment could provide a short duration pulse, and this pulse could be used to accurately map a waveguide system.

By using a high-speed sampling oscilloscope capable of viewing r-f voltage from d-c to X-band instead of unbiased crystal-detected pulses, much lower incident power levels were sufficient to produce displays of waveguide obstruction reflections. This, coupled with the fast rise time of such an oscilloscope, provided obstruction location accuracies to within one-half foot on occasion, with overall accuracies of within one foot. A determination could be made of waveguide flanges, bends, switches, antennas and other construction devices. Further, even small dents or amounts of foreign material in the waveguide were noticeable and located. Waveguide faults would therefore, if present, be easily detected, measured, and located. When new waveguide systems are installed, r-f voltage pulse reflectometry could be used to time, calibrate and insure proper operating conditions of such a system.

The r-f voltage pulse system is superior to those using d-c pulses since most of the bandwidth needed is easily available within waveguide limitations. Delay distortion was not a factor and did not degrade overall results with waveguide runs to 100 feet. Further, the small incident pulse power precluded interference with outside systems. Moreover, improvements upon this existing system could be made so as to allow coherent pulse methods to be used. A device capable of higher pulse repetition frequencies with phase-coherent pulses such as a Gunn diode modulated by short d-c spikes might be used as a signal source in the system. The coherence of the r-f signal from pulse to pulse produced by such an oscillator, plus the high pulse-repetition frequencies, would allow the viewing and measuring of not only obstruction reflection amplitudes and location, but also phase characteristics. A trigger count-down unit would be needed to view the coherent signal and this is presently available.

Templates for the conversion of scope presentations from time and amplitude directly to distance and reflection coefficients could be designed. These templates would allow real-time direct information and such a system could truly be called time-domain reflectometry.

BIBLIOGRAPHY

1. Shoemaker, W. B., Nanosecond R-F Pulses for Waveguide Fault-Finding, Master's Thesis, Naval Postgraduate School, Monterey, California, 1968.

2. Hewlett Packard Company, 1969 Solid State Circuit Devices, 1969

3. Naval Research Laboratory Report 1870, Nanosecond Pulse Radar as a Measuring Tool, by G. F. Myers, May 1968.

4. Ray, R. L., A Nanosecond Microwave Burst Generator Using Resonant Build Up for Output Peak Power Enhancement, Master's Thesis, Naval Postgraduate School, Monterey, California, 1969.

5. Dougal, A. A. and Goldstein L., "The Spike in Transmit-receive (TR) Tubes," IRE Transactions Electron Devices, v. ED-3, p. 142-148, July, 1956.

6. Electronic Tubes, Five Star and Special Purpose Types, General Electric Company, Tube Department.

7. Montgomery, C. G., and others, Principles of Microwave Circuits, p. 34, McGraw-Hill, 1948.

8. Reference Data for Radio Engineers, 5th ed., p. 23-26. International Telephone and Telegraph Corporation, 1968.

9. Microwave Transmission Design Data, p. 68,Sperry Gyroscope Company, May 1944.

10. Ginzton, E. L., Microwave Measurements, McGraw-Hill, 1957.

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13. ABSTRACT

The testing of waveguide systems was demonstrated using nanosecond r-f pulses. Pulse generation was effected by d-c coupled pulse grid modulation of a traveling-wave tube. This d-c modulation pulse was produced through the use of a fast thyratron circuit. Resultant r-f voltage pulses were used to drive a waveguide system and reflections from waveguide obstructions were viewed on a high-speed sampling oscilloscope. The location and reflection coefficients of obstructions were then obtained from measurements taken on the oscilloscope face.

14 KEY WORDS	LINK A		LINK B		LINK C	
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